

The Protein That Should Not Be There

Measured Collagen Decay Kinetics and the Problem of Soft Tissue in a Hell Creek Edmontosaurus

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ABSTRACT

Tuinstra et al. (2025) reported collagenous remnants in an Edmontosaurus sacrum (UOL GEO.1) from the Upper Cretaceous Hell Creek Formation, supported by cross-polarized microscopy, hydroxyproline quantification, and LC-MS/MS peptide data. We take endogeneity as the working premise and ask a narrower question: what do published collagen-decay kinetics actually permit us to infer about preservation time? Accelerated thermal-degradation experiments provide Arrhenius-based rate estimates specifically for this. A 2025 conference report gives preliminary 25 C neutral-aqueous half-lives of 296 years for avian bone and 1,086 years for mammalian bone; an earlier author-reported bovine extrapolation gives 21,012 years at 15 C under favorable conditions. Under a simple first-order model, 1% of the initial collagen pool would remain after approximately 1,967, 7,215, and 139,600 years, respectively. These are residual-fraction benchmarks, and not reliant on other dating methods. A reptile-specific long-term decay half-life comparable to the avian and mammalian estimates was not located in the literature. However, an archaeological tortoise specimen yielded only 0.6 wt% collagen and was conventionally dated at approximately 11.2 - 11.7 ka, demonstrating reptilian collagen recovery below the conventional 1 wt% bone-yield benchmark. We also incorporate experimentally supported stabilization mechanisms, exceptional fossil collagen survival into the Pleistocene and Pliocene, and the 2025 correction to the Edmontosaurus article. The result is a very constrained conclusion: existing kinetic data can be used to uniquely date the specimen, and define a quantitative preservation problem that can be tested by reptile/archosaur decay experiments under realistic taphonomic conditions. A conditional avian-rate back-calculation yields an illustrative 3.6 - 4.4 ka range, but that calculation is not a direct date and depends on several unverified assumptions.

Keywords: collagen decay; protein kinetics, arrhenius equation; Edmontosaurus, Hell Creek Formation, Dinosaur soft tissue, dinosaur bone, fossil preservation, decay rates, evolution

1. Introduction

Reports of endogenous protein and soft-tissue-like structures in fossil vertebrate bone have become increasingly detailed, yet the chemistry of long-term protein survival remains contested. The 2025 study of an exceptionally preserved Edmontosaurus sacrum from the Hell Creek Formation is especially useful because the authors combined several analytical methods rather than relying on a single signal. Their work therefore creates a focused kinetic question: if collagenous material is endogenous, how should its preservation be evaluated against experimentally measured or experimentally anchored decay behavior?

The original version of this paper treated several model outputs too strongly. In particular, it described a 1% residual level as a general analytical detection floor, treated Arrhenius projections as though they were direct long-duration measurements, and converted an avian decay estimate into a narrow burial date. This revision separates observation from extrapolation. It also incorporates the 2025 correction to the Edmontosaurus article, adds the closest reptilian comparison we could locate, and directly addresses experimental preservation mechanisms such as iron-mediated and glycation-associated crosslinking.

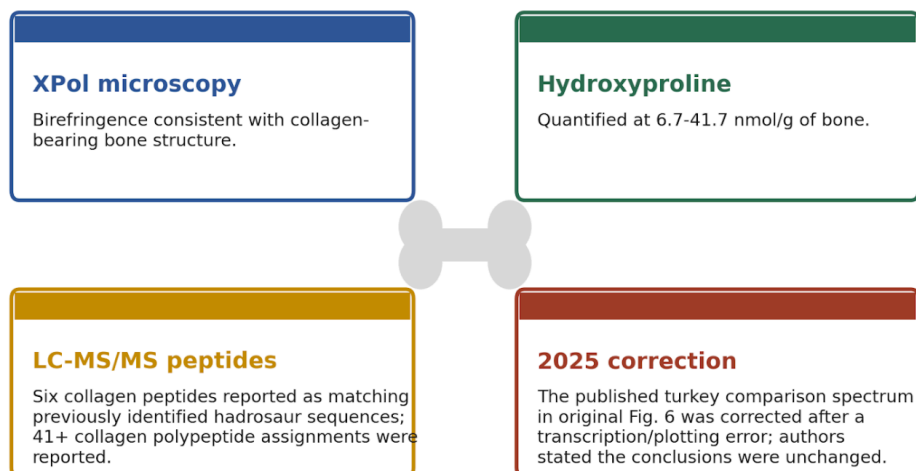
Our central question is not whether one equation can independently date UOL GEO.1. It cannot. The useful question is whether existing decay data, preservation experiments, and empirical fossil survival are mutually consistent, and which additional measurements would be needed to turn the collagen signal into a defensible chronological constraint.

2. What was actually recovered

Tuinstra et al. published their study in Analytical Chemistry in 2025, not 2024. The paper reports cross-polarized light microscopy (XPol) birefringence consistent with collagen-bearing bone structure, LC-MS quantification of hydroxyproline, and LC-MS/MS peptide sequences matching collagen sequences previously reported from dinosaur material. The study reports hydroxyproline concentrations of 6.7 - 41.7 nmol/g of bone and describes multiple collagen peptide/polypeptide assignments. These observations are the empirical starting point for the present analysis.

The authors argued that the short, degraded character of the molecular signal and the agreement among different methods favor an endogenous, degraded source over simple fresh contamination. For the purpose of this paper we accept that conclusion as a working premise. If the material were instead exogenous contamination, the kinetic question considered here would largely disappear.

Figure 1. Evidence reported for endogenous collagen in Edmontosaurus UOL GEO.1



Source basis: Tuinstra et al. (2025) and the published 2025 correction.

Figure 1. Summary of the principal evidence reported for collagenous material in *Edmontosaurus* UOL GEO.1. The correction note is included because the original turkey comparison spectrum in Figure 6 was later replaced after a transcription/plotting error. Tuinstra et al. stated that the corrected spectrum did not alter their conclusions.

2.1 The 2025 correction

A formal correction published in April 2025 reported that the turkey spectrum shown in the original Figure 6 had inadvertently been generated from the *Edmontosaurus* data set during transfer into the plotting software. The figure was replaced using the correct turkey data. The authors stated that the raw data and overall conclusions were unaffected. Because this paper relies on the broader multi-method case rather than that single plotted comparison, the correction should be acknowledged but does not by itself invalidate the endogeneity argument.

3. Collagen decay: what is measured and what is extrapolated

Collagen is unusually stable for a protein, but it is not chemically inert. Peptide-bond hydrolysis, oxidation, crosslinking, microbial activity, water availability, mineral association, pH, and temperature all influence its postmortem fate. Laboratory studies commonly accelerate degradation at elevated temperatures and then use Arrhenius relationships to estimate reaction behavior at lower temperatures. This is a standard kinetic strategy, but the low-temperature centuries-to-millennia values are projections anchored by experiments, not direct observations lasting centuries.

Thomas et al. (2023) demonstrated that ATR-FTIR measurements are sensitive to thermally induced loss of bone collagen and reported Arrhenius behavior for experimentally degraded bone. An earlier article by *Thomas* (2019), based on related experimental work, reported a bovine bone-collagen half-life of 21,012 years at 15 C under favorable modeled conditions.

Johnston et al. (2025), in a conference abstract rather than a full peer-reviewed article, reported preliminary half-lives of 1,086 years for mammalian bone and 296 years for avian bone at 25 C in a neutral aqueous environment. The same abstract states that the laboratory is measuring mammalian, avian, and reptilian bones, but it does not provide a numerical reptilian half-life. Because these values are preliminary, they are useful as sensitivity cases rather than as settled universal constants.

Source / status	Material & condition	Reported half-life	How used here
Johnston et al. 2025	Avian bone, 25 C aqueous	296 y	Preliminary sensitivity
Johnston et al. 2025	Mammalian bone, 25 C aqueous	1,086 y	Preliminary sensitivity
Thomas 2019 (author estimate)	Bovine bone, 15 C model	21,012 y	Generous sensitivity
Buckley & Collins 2011	Optimal burial model, 10 C	1% after 0.2 - 0.7 Ma	Independent comparison

Table 1. Decay values and their evidentiary status.

4. A necessary terminology correction: two different “1%” quantities

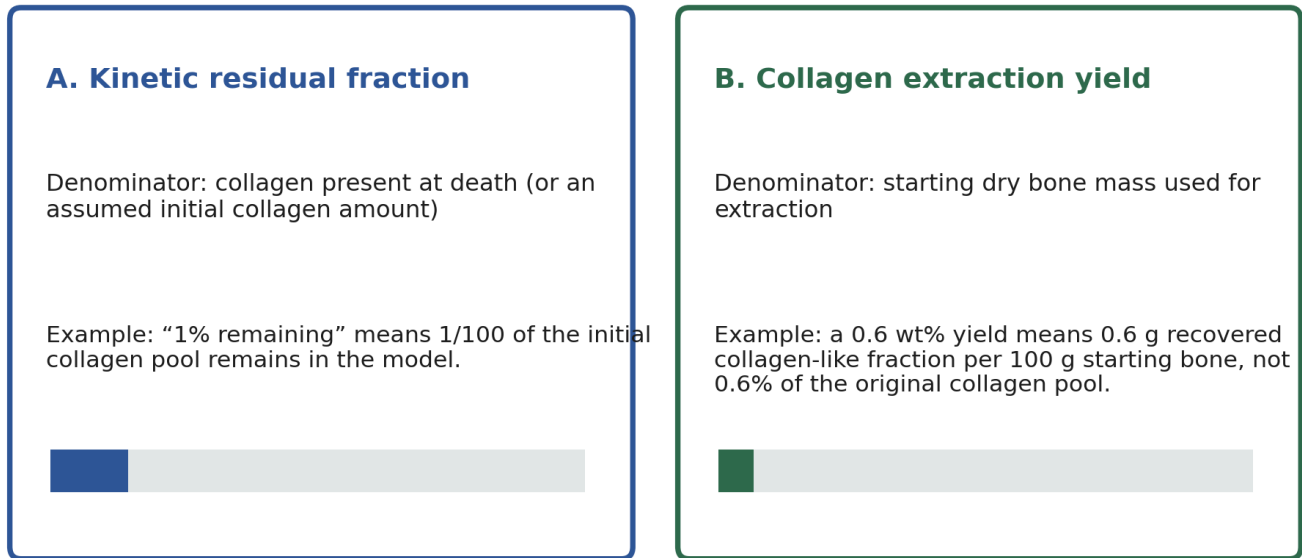
The phrase “1% collagen” is used in two very different ways in the literature, and conflating them creates a serious error.

First, a kinetic model may ask what fraction of the collagen present at death remains after some elapsed time. In that usage, 1% means 1% of an assumed initial collagen pool.

Second, radiocarbon laboratories report collagen yield as the mass of extracted collagen relative to the starting bone mass. In that usage, 1 wt% means roughly 1 mg of extracted collagen per 100 mg of starting bone.

Fresh bone contains roughly 20-25 wt% collagen, so a bone yielding 1 wt% collagen has not necessarily retained 1% of its original collagen. If a fresh-bone baseline of 22 wt% were appropriate, a 1 wt% extraction yield would correspond to roughly 4.5% of that baseline before any allowance for extraction efficiency, heterogeneity, or chemical alteration. Accordingly, the 1 wt% radiocarbon screening criterion is a sample-quality convention, not a universal analytical detection limit and one we hold little value in since carbon dating past just a couple thousand years is highly unreliable.

Figure 2. Two different meanings of “percent collagen”



These quantities must not be placed on the same decay curve without an explicit conversion model.

Figure 2. *The kinetic residual fraction and the radiocarbon collagen-yield percentage use different denominators. They should not be interchanged without an explicit conversion model.*

5. Reptilian comparison: a value below 1%, but not the same 1%

A direct reptile-specific long-term collagen decay half-life comparable to the preliminary avian and mammalian values was not located in the literature reviewed for this paper. This is an important missing control. Non-avian dinosaurs are archosaurs, so neither a bird nor a mammal should automatically be assumed to provide the exact kinetic behavior of hadrosaur bone under burial conditions.

Two reptilian studies nevertheless add useful context. Wood et al. (2008) characterized collagen isolated from American alligator bone and found it to be typical type I collagen, with denaturation temperatures near 38 C. That study establishes relevant reptilian collagen chemistry but does not provide a postmortem decay half-life.

More directly relevant to the requested below-1% comparison, Loftus, Sealy, and Lee-Thorp (2016) reported a tortoise carapace specimen (OxA-32684) from Byneskranskop 1, South Africa, with a collagen yield of only 0.6 wt% of starting bone mass.

The specimen returned a conventional radiocarbon age of 10,015 +/- 45 BP, with a calibrated range of approximately 11,695-11,245 cal BP, and a C:N ratio of 3.3. The authors considered the result acceptable despite the low yield. This is a genuine reptile example below the conventional 1 wt% collagen-yield benchmark, found directly in the published literature.

Figure 3. Reptilian collagen: what is known and what is still missing

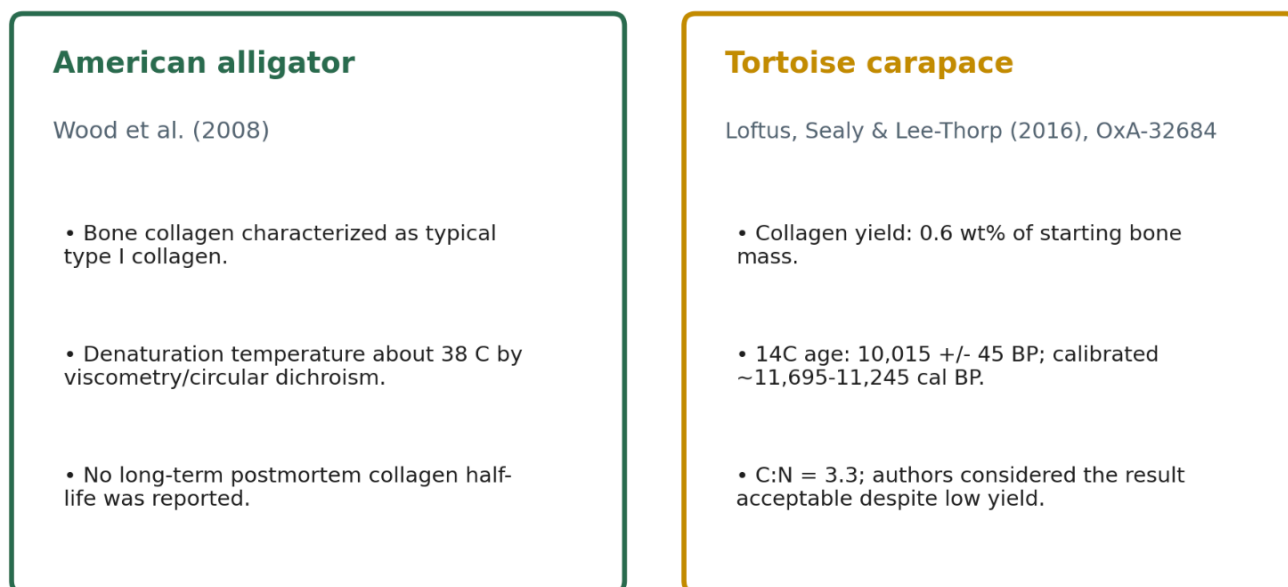


Figure 3. *Reptilian comparison. The tortoise result supplies the requested empirical reptile example below 1 wt% collagen yield; it must remain separate from percent-original-collagen decay curves.*

6. Quantitative model

For transparency, the calculations below use the simplest exponential first-order model. If H is a half-life and t is elapsed time, the residual fraction f is:

$$f(t) = 2^{(-t/H)}$$

$$t \text{ at residual fraction } p = H \times \log_2(1/p)$$

At $p = 0.01$, $\log_2(100) = 6.643856$. Therefore a modeled collagen pool reaches 1% of its initial value after approximately 6.64 half-lives. This equation is a sensitivity model, not a complete fossilization model; it assumes a constant effective half-life and does not explicitly represent changing water activity, mineral sealing, crosslink formation, microbial ecology, or thermal history.

6.1 The 1% residual benchmark

Scenario	Half-life	Time to 1% of initial pool
Avian, 25 C aqueous (preliminary)	296 years	1,967 years
Mammalian, 25 C aqueous (preliminary)	1,086 years	7,215 years
Bovine, 15 C favorable model	21,012 years	139,601 years

Table 2. *Simple first-order 1% residual benchmarks. These values do not define an analytical detection floor.*

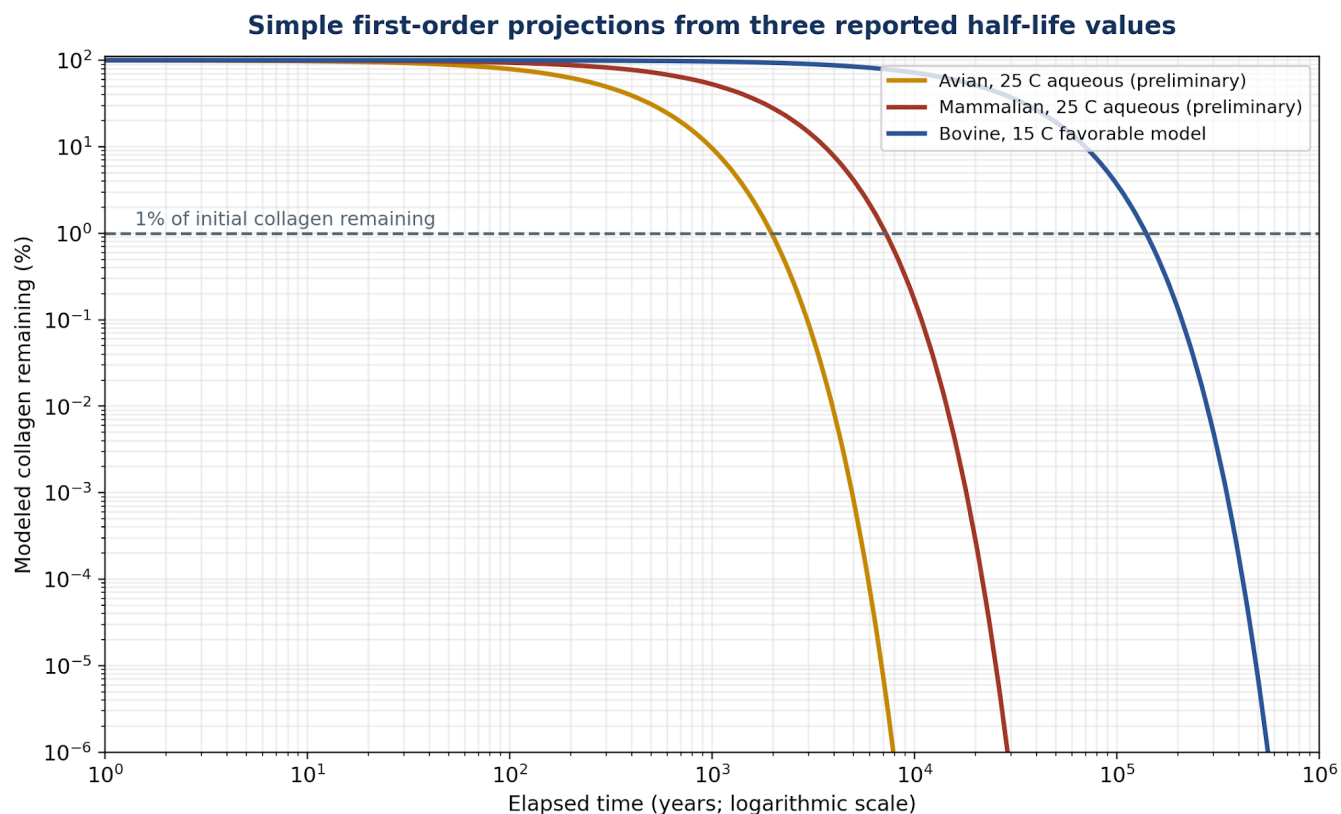


Figure 4. Exponential projections from three reported half-life values. The avian and mammalian numbers are preliminary conference results; the 21,012-year value is an author-reported favorable bovine extrapolation.

6.2 Conditional hydroxyproline back-calculation

The Edmontosaurus study reported 6.7 - 41.7 nmol hydroxyproline per gram of fossil bone. To explore the magnitude of that signal, the original paper compared it with an illustrative fresh-bone baseline. If fresh bone is assumed to contain 200 mg collagen/g bone and hydroxyproline is assumed to comprise approximately 13.5% of collagen by mass, the implied fresh hydroxyproline concentration is about 206,000 nmol/g (approximately 200,000 nmol/g when rounded).

With that assumed baseline, 41.7 nmol/g corresponds to approximately 0.020% and 6.7 nmol/g to approximately 0.003% of the baseline hydroxyproline amount. Applying the preliminary 296 year avian half-life to those fractions produces approximately 12.2 - 14.9 half-lives, or **roughly 3,600 - 4,400 years**.

Interpretation limit: 3,600 - 4,400 years is an illustrative conditional result, not a direct date. It assumes the fresh-bone baseline, stable first-order kinetics, an avian rate appropriate to hadrosaur collagen, and an appropriate thermal/hydrological history. Changing any of these assumptions changes the inferred time.

6.3 The 66-million-year extrapolation

A separate sensitivity calculation asks what would happen if the most favorable 21,012 year effective half-life remained constant for 66 million years. The interval contains approximately 3,141 half-lives. The modeled residual fraction is then 2^{-3141} , approximately 10^{-946} . For comparison, the observable universe is often estimated to contain on the order of 10^{80} atoms. The numerical gap between 10^{-946} and 10^{80} is about 866 orders of magnitude! This calculation does not itself establish a burial date, but it illustrates the extraordinary magnitude of preservation that a 66-million-year interpretation must accommodate even when the most favorable kinetic estimate considered here is granted.

The geological setting makes that comparison still more important. UOL GEO.1 was recovered from the Hell Creek Formation of Harding County, South Dakota, a formation interpreted as a low-lying fluvial and coastal-plain environment composed of river channels, floodplains, wetlands, swamps, and periodically water-saturated sediments, rather than a persistently frozen or hyper-arid preservation setting. Hell Creek strata in this region have specifically been interpreted as swamp and coastal-plain deposits, while regional sedimentological studies describe channel sands, overbank mudstones, and floodplain deposits produced by active river systems.

Because water promotes hydrolytic cleavage of peptide bonds, repeated exposure to pore water would ordinarily work against, not in favor of, indefinite collagen preservation. Although the precise microenvironment surrounding this particular sacrum has not been published in sufficient detail to call it a river-channel burial specifically, there is no documented basis for treating it as having experienced continuous cold, exceptional aridity, or permanent isolation from water. The remarkable point, therefore, is not merely that collagen is present after an assigned 66 million years, but that it occurs in a specimen derived from a geological setting in which the very environmental factors expected to accelerate protein degradation were potentially abundant.

7. Hell Creek taphonomy and preservation mechanisms

Since the Hell Creek Formation represents a fluvial/coastal-plain depositional system rather than a continuously frozen High Arctic setting required for optimal preservation. Water availability is also relevant because hydrolysis and transport of reactants depend on the presence and activity of water. However, the complete post-burial temperature and pore-water history of the specific UOL GEO.1 sacrum is not directly measured over its entire geological history. Statements that the fossil experienced one fixed 'wet' or 'dry' kinetic condition should be avoided. The fact still remains that the location is not favorable to preservation and both wet and hot dry temperatures accelerate the decay process.

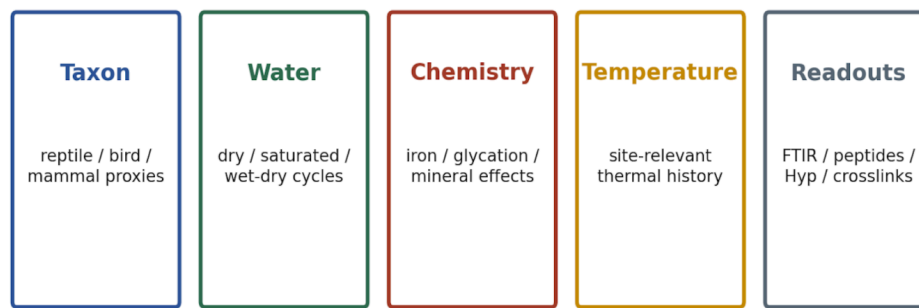
Schweitzer et al. (2014) experimentally showed in laboratory settings that hemoglobin/iron associated chemistry could stabilize an ostrich blood-vessel model by more than two hundredfold relative to untreated tissue under their laboratory conditions. *Boatman* et al. (2019) tested Fenton-chemistry and glycation treatments of extant chicken tissues and found crosslink patterns consistent with mechanisms that could contribute to stabilization of *T. rex* vessel structures. Mineral association and early diagenetic chemistry may likewise reduce molecular mobility or protect portions of proteins.

These mechanisms are not merely hypothetical placeholders: some have experimental support. The unresolved question is quantitative. The cited experiments do not yet provide a specimen-specific decay law demonstrating how much intact or sequenceable collagen should remain in a Hell Creek bone after 66 Ma under the actual thermal, hydrological, microbial, mineral, and redox history. Conversely, a young-age model cannot just import an avian aqueous half-life and claim a direct burial date either. Both interpretations require a calibrated taphonomic model. We will take our's a step further and make predictions and use direct observation to confirm our decay suspicions.

8. What would make the kinetic test decisive?

The most informative next experiment is the one highlighted by the literature gap itself: publish reptilian and archosaur-proxy bone-collagen decay constants under controlled conditions, then repeat the experiments while systematically introducing proposed stabilizing variables. The resulting data should be modeled with uncertainty and validated against archaeological samples of known age and burial history.

Experiments that would make the *Edmontosaurus* test decisive



Goal: derive a specimen-relevant kinetic law, then compare the predicted preservation to the measured fossil signal.

This design directly tests both accelerated decay and proposed stabilization mechanisms instead of assuming either one is sufficient.

Figure 5. *A direct experimental program for converting the present qualitative dispute into a quantitative test.*

At minimum, future work should report the raw decay curves, activation energies, confidence intervals, sample mineralogy, pH, water activity, microbial controls, crosslink chemistry, and multiple analytical readouts. If such experiments can reproduce the persistence of sequenceable collagen over geologically relevant equivalent times under realistic Hell Creek conditions, the kinetic objection would be substantially weakened. If they cannot, the conventional age interpretation would face a sharper quantitative preservation problem.

9. Authorial interpretation and limits

We present a manuscript that approaches the data from a biblical creationist framework. Within that framework, a burial age of only several thousand years is expected with a post-Flood chronology. The conditional 3,600 - 4,400 year calculation described above is of particular interest to us as it is what our model predicts to find. Other such cases exist and you can find them published as well (Budinsky et al. 2026, M. Nailor 2026)

10. Conclusion

The 2025 Edmontosaurus study presents a serious and interesting preservation problem because it reports multiple lines of evidence for endogenous collagenous remnants in a fossil assigned to the latest Cretaceous. Existing accelerated-degradation experiments show that bone collagen can decay rapidly under warm aqueous conditions, and even faster when wet, while only the most favorable cases are that of low-temperature models and exceptional fossil cases. Three things favor our study; First, 1% of the original collagen pool must be distinguished from a 1 wt% collagen extraction yield. Second, low-temperature half-lives derived from accelerated degradation are Arrhenius-based projections rather than direct multi-millennial measurements. Third, the requested reptilian comparison exists below 1% only in the collagen-yield sense: a directly dated tortoise carapace yielded 0.6 wt% collagen at approximately 11.2 - 11.7 ka.

Under a simple constant-half-life model, the three sensitivity cases examined here reach 1% of their assumed initial collagen pools at approximately 1,967, 7,215, and 139,600 years. A 66 Ma extrapolation of the 21,012 year model yields an extremely small residual fraction (10^{-946}). Our conclusion is narrower and more testable: the Edmontosaurus collagen signal requires a quantitative preservation explanation, and the decisive missing evidence is a specimen-relevant, reptile/archosaur-calibrated kinetic model that incorporates experimentally measured stabilization and realistic burial history. As for the data that we do have and utilized in this study on avian decay, the results fall exactly where expected in our model.

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